IN THE SPECIFICATION

At the beginning of the specification, delete the word "TITLE."

Replace present paragraph [0019] with the following new paragraph [0019]:

[0019] In an advantageous application of the method, the cascade comprises an axial flow impeller and the lifting elements comprise a plurality of impeller blades arranged around a hub capable of rotating on an axis, and the number of cycles is selected to provide a reduced frequency k from 0.1 to a value on the order of magnitude of 1, ~~O(1) > k > 0.1~~ for all sections of each said blade over a predetermined operating range of said impeller, k being defined as follows:

$$k = \left(\frac{M\Omega}{V}\right)\left(\frac{c}{2}\right)$$

where k = reduced frequency, M is the number of cycles per revolution of the impeller, Ω is the impeller angular velocity in radians/sec., c is the chord length in feet of the impeller blade airfoil section being considered, and V is the average total velocity of the air flow in ft./sec. approaching the blade. In particular, the directing step can be implemented by a stator with a plurality of stator blades having airfoil cross-sections arranged around the axis upstream of the impeller, and the impeller blades have a predetermined airfoil cross-section that exhibits steady aerodynamic stall when flow approaches the blades at an angle above a steady-state stall angle. The parameter is a flow angle at which the flow is directed to the impeller, and each stator blade is oriented at a predetermined turning angle that varies the flow angle circumferentially around the axis from 10° below to 20° above the steady-state stall angle.

After paragraph [0027], add the following new paragraphs:

FIGURE 8 is a side view of an alternate embodiment of the fan shown in FIGURE 2.

FIGURE 9 illustrates a multi-stage embodiment of the invention.

FIGURES 10A and 10B depict additional embodiments of the invention incorporated into an axial flow device, wherein FIGURE 10A is a cascade view of an embodiment in which the airfoil configuration of the stator blades varies circumferentially around the stator axis and FIGURE 10B is a cascade view of an embodiment in which the spacing of the stator blades varies circumferentially around the stator axis.

FIGURE 11A shows an embodiment of the invention as applied to a marine propulsor, and FIGURE 11B depicts skewed rotor blades incorporated into the marine propulsor in accordance with another aspect of the invention.

Replace present paragraph [0028] with the following new paragraph [0028]:

[0028] FIGURE <u>12</u> [[8]] depicts an alternate embodiment of the invention incorporated in a centrifugal compressor.

Replace present paragraph [0035] with the following new paragraph [0035]:

[0035] Each stator blade also has an airfoil cross-section and its camber line forms a turning angle θ relative to the fan axis and therefore to the velocity V_∞ of the air entering the fan stage. In accordance with <u>this embodiment of</u> the invention, the turning angle of the blades within each group gradually increases from θ_1 and then gradually decreases

from a maximum value to θ_7. Those skilled in the art will recognize that the cyclic variations in flow can be provided by variations in other geometric properties of the blades, such as camber, chord length, airfoil shape, and/or blade spacing.

Replace present paragraph [0039] with the following new paragraph [0039]:

[0039] FIGURE 5 also illustrates an inherent feature of apparatus incorporating the present invention, namely that the cyclic variations in flow can introduce periodic variations in thrust when the invention is applied to devices such as propellers and marine propulsors. While these variations are undesirable, the nature of the invention also inherently includes a manner of minimizing variations in the thrust. That is, since the flow variations are cyclical in nature, their periodicity can be controlled by carefully selecting the number and properties of the propeller blades and of the upstream device that directs the flow into the propeller. Moreover, the plot in FIGURE 5 represents the lift generated by a single rotor blade. Accordingly, it will be immediately apparent that by judicious selection of the number and properties of the components of the invention, the phases of the periodic lift forces on all of the individual propeller blades can be controlled to minimize the difference between the total maximum and minimum thrust generated by all of the blades as the propeller rotates. Conversely, there may be applications in which it is desirable to maximize these thrust variations. For example, such thrust variations can be used in a pump to provide a pulsating water jet from a pressure washer to enhance its cleaning action, or thrust variations could be used to increase acoustic signatures of active acoustic countermeasure devices such as acoustic decoys.

Replace present paragraph [0050] with the following new paragraph [0050]:

[0050] Even though the discussion above of the general principles underlying the invention uses an embodiment incorporating just a rotating cascade to illustrate the invention, those skilled in the art will readily appreciate that the invention can be applied in a variety of ways to myriad different apparatus. For example, the stator used to vary cyclically the angle at which flow in directed to the rotor can be replaced by any device that provides a cyclic variation in a flow parameter that will cause each rotor lifting element to cycle through a flow regime in which the flow begins to separate from the lifting element, as shown in FIGURE 1, and then reattaches thereto. With that it mind, it will be appreciated that the stator discussed above can be replaced with a counter-rotating rotor with blades corresponding to the stator blades 26 discussed above. FIGURE 8 illustrates an embodiment of the invention in which rotor blades 28', corresponding to the stator blades 26 in FIGURES 2 and 3, are attached to a disk 34'. As noted, the disk 34' is mounted for counter-rotation (that is, in the opposite direction) relative to the disk 34, thus providing a counter-rotating second axial flow impeller upstream of the first impeller provided by the blades 28. In this embodiment, the hub 32' is shorter axially as compared to the hub 32. The ~~In fact, the~~ operational principles discussed above using a stator to illustrate the invention apply equally to an embodiment like that shown in FIGURE 8 using a counter-rotating impeller 26' in place of the stator 26. In addition, an implementation of the invention using a counter-rotating impeller can also be retrofit to an existing apparatus.

Replace present paragraph [0051] with the following new paragraph [0051]:

[0051] The invention can be realized in myriad other forms, as well. As one example, the embodiment discussed above in connection with FIGURE 2 is a single stage fan, with one rotor and one stator. The invention is applicable to a multiple stage device, in which the flow exiting the rotor of one stage is directed into the stator of a downstream stage. FIGURE 9 depicts such an embodiment, in which the compressor 40 of a jet engine like that shown in FIGURE 2 is constructed in accordance with the principles of the present invention. In that regard, the first stage of the compressor includes a stator comprising blades 42 and a rotor comprising blades 44. The compressor rotor blades 44 are conventional and correspond to the rotor blades 28 of the fan discussed in connection with FIGURES 2 and 3. The compressor stator blades 42 are arranged to orient the working medium relative to the compressor rotor blades 44 in a fashion similar to that discussed above in connection with the manner in which the fan stator blades 26 orient the working medium relative to the fan rotor blades 28. Likewise, the stator blades 46 of the second compressor stage can be arranged in the same fashion relative to the second stage rotor blades (not shown). In this manner, the flow exiting the outlet of the axial flow impeller of one stage is directed to the stator of a downstream stage. ~~In addition, the airfoils comprising the blades of the stator (or counter-rotating impeller) can be varied by changing geometric properties other than turning angle. For example, the blades' airfoil configuration (such as camber, chord length, etc.), the spacing between adjacent blades, and other properties can be controlled in the manner discussed above to periodically effect the increased lift associated with delayed stall. Still other variations are possible, in that the geometric~~

~~properties of any given blade can be controlled during operation to account for different operating conditions. This could be accomplished in a number of ways. One convenient structure for making adjustments during operation could use shape-memory alloy tabs or tab actuators, as discussed in U.S. Patents No. 5,752,672 to McKillip and No. 6,345,792 to Bilanin et al., to change the blades' turning angles. The disclosures of those patents relating to the manner of implementing such structure are incorporated herein by reference. Such tabs could be incorporated on FIGURE 3's stator blades 26 to selectively change their turning angles to adjust for operation of the stator/rotor combination under off-design conditions.~~

After paragraph [0051], add the following new paragraphs:

In addition, the airfoils comprising the blades of the stator (or counter-rotating impeller) can be varied by changing geometric properties other than turning angle. For example, the blades' airfoil configuration (such as camber, chord length, etc.), the spacing between adjacent blades, and other properties can be controlled in the manner discussed above to periodically effect the increased lift associated with delayed stall. FIGURE 10A shows an embodiment of the invention in which the chord length of the stator blades is varied cyclically. In FIGURE 10A the stator blades 26a are arranged as described in connection with FIGURE 3, in multiple groups M, each group having K blades. The notation used in FIGURE 10A to identify the stator blades is "$26a_{M,K}$." Groups M = 1 and M = 2 are depicted in FIGURE 10A, but as in FIGURE 3, there can be any number of such groups. Likewise, $K_n = 7$ in FIGURE 10A, but those skilled in the art will appreciate that the number of stator blade groups M, the number K of

individual stator blades in each group, and the number of rotor blades, are all chosen to obtain the desired performance under specified operating conditions. Each stator blade 26a has an airfoil cross-section, and the camber line of all of the blades forms the same turning angle θ relative to the fan axis and therefore to the velocity V_∞ of the air entering the fan stage. In accordance with this embodiment of the invention, the chord length of the blades within each group gradually increases from a nominal chord c (depicted here as the chords of blades $26a_{1,2}$ and $26a_{2,2}$). As an example of a typical variation, the chord lengths of the blades in each group M of an apparatus in accordance with this embodiment might be 0.9c, 1.0c, 1.1c, 1.2c, 1.1c, 1.0c, and 0.9c.

FIGURE 10B shows an embodiment in which the spacing between the blades is varied cyclically in accordance with the principles of the invention. The notation used in FIGURE 10B to identify the stator blades is "$26b_{M,K}$." Groups M = 1 and M = 2 are depicted in FIGURE 10B, but as in FIGURES 3 and 10A, there can be any number of such groups. Likewise, $K_n = 7$ in FIGURE 10B, but those skilled in the art will appreciate that the number of stator blade groups M, the number K of individual stator blades in each group, and the number of rotor blades, are all chosen to obtain the desired performance under specified operating conditions. Each stator blade 26b has an airfoil cross-section, and the camber line of all of the blades forms the same turning angle θ relative to the fan axis and therefore to the velocity V_∞ of the air entering the fan stage, and the blades all have the same chord length c. In accordance with this embodiment of the invention, the spacing between the blades within each group gradually increases from a nominal spacing (depicted here as the distance 1.0c between blades $26b_{1,2}$ and $26b_{1,3}$ and between blades $26b_{2,2}$ and $26b_{2,3}$). As an example of a

typical variation, the spacing between adjacent blades in each group M of an apparatus in accordance with this embodiment might be 0.9c (between blades $26b_{M,2}$ and $26b_{M,3}$) and then 1.0c, 1.1c, 1.2c, 1.1c, 1.0c, and 0.9c between successive pairs of blades in each group.

Still other variations are possible, in that the geometric properties of any given blade can be controlled during operation to account for different operating conditions. This could be accomplished in a number of ways. One convenient structure for making adjustments during operation could use shape-memory alloy tabs or tab actuators, as discussed in U.S. Patents No. 5,752,672 to McKillip and No. 6,345,792 to Bilanin et al., to change the blades' turning angles. The disclosures of those patents relating to the manner of implementing such structure are incorporated herein by reference. Such tabs could be incorporated on FIGURE 3's stator blades 26 to selectively change their turning angles to adjust for operation of the stator/rotor combination under off-design conditions.

Replace present paragraph [0052] with the following new paragraph [0052]:

[0052] In addition, the rotor blades [[28]] can be skewed, that is, angled in the direction of the rotational axis, which, as is known, will introduce a radial component into the flow downstream of the blades. FIGURES 11A and 11B depict a <u>marine propulsor having a</u> rotor with skewed blades in accordance with this aspect of the invention. <u>The construction of marine propulsors is well known those of ordinary skill in this art, as seen in U.S. Patents No. 5,078,828, No. 5,252,875, No. 5,289,068, and No. 5,607,329, the latter patent being an example of a marine propulsor with skewed rotor blades as</u>

shown in Figure 10 thereof. As seen in FIGURE 11A, a typical marine propulsor 20m includes an annular duct wall 23m forming an inlet 24m that introduces water into the marine propulsor. The duct wall encloses a row of stationary vanes 26m and a rotating propeller comprising a plurality of propeller blades 28m. As seen in FIGURE 11B, which is a view looking axially downstream within the marine propulsor, the propeller blades 28m are skewed. Based on insect studies like those already discussed, a radial flow component in the flow directed toward the cascade of lifting elements should stabilize the leading edge vortex generated at the onset of stall. That should likewise prolong the duration of the enhanced-lift condition. If the device for introducing a cyclic variation in the flow directed to the rotor blades 28 is itself a counter-rotating rotor, as discussed above, its blades can be skewed either instead of the rotor blades 28, or both the rotor blades 28 and the blades of the upstream counter-rotating rotor can be skewed.

Replace present paragraph [0054] with the following new paragraph [0054]:

[0054] The existence of delayed stall is modeled in accordance with the conventional dimensionless parameter "reduced frequency of oscillation," adapted for use with the present invention by defining it in relation to the blade semi-chord as follows:

$$k = \left(\frac{M\Omega}{V}\right)\left(\frac{c}{2}\right)$$

where k = reduced frequency, M is the number of inlet flow cycles per revolution, Ω is the rotor angular velocity in radians/sec., c is the chord length of the blade airfoil section being considered, and V is the average total velocity of the air flow approaching

the rotor blade (see FIGURE 4). It is known that with the proper mean incidence, and pitching amplitude around the mean incidence, an airfoil is in a delayed lift enhancement regime for $k > 0.01$, and that the degree of lift enhancement generally increases as k increases to a maximum <u>value on the order of magnitude of 1.</u> ~~around k = O(1).~~ It is believed that the advantages of delayed stall lift enhancement will be achieved when <u>k is from 0.1 to a value on the order of magnitude of 1</u> ~~O(1) > k > 0.1~~ over the entire operating range of a particular rotor.

Replace present paragraph [0055] with the following new paragraph [0055]:

[0055] In applying the present modeling technique, the steady rotor stall operating conditions are first determined using conventional methods. For a particular rotor geometry (airfoil cross-sectional shape, chord length, pitch angle, radius, etc.), rotational speed, mass flow rate through the rotor and free stream velocity (V_∞), the average total velocity V can be determined. The reduced frequency k is then set to <u>the order of magnitude of 1</u> ~~be O(1)~~ by specifying M (the number of flow variation cycles per rotor revolution) in accordance with the above equation, rearranged as follows:

$$M = \left(\frac{2Vk}{\Omega c} \right)$$

M is then rounded to the nearest integer, which is required by definition to make the inflow variation periodic in 360°. Next, the inlet flow cycle is defined by considering local rotor velocity triangles as a function of circumferential position. See FIGURE 4. Starting with steady rotor stall onset incidence, a circumferential variation in the inlet flow is superimposed on this mean flow, which variation may include any combination

of swirl variation and/or axial flow variation such that the resulting local rotor flow incidences will cycle between 10° below and 20° above the steady stall incidence. With the flow incidence range thus defined, the turning angles of the upstream stator blades or inlet guide vanes are chosen to provide an inlet flow that yields the desired cyclic variation in the rotor incidence. In theory, the incidence would be raised as rapidly as possible in the cycle, held at the high incidence for approximately half the cycle, and then dropped back to a low value just long enough for the flow on the rotor blade to recover (reattach). In practice, the inlet flow cyclic structure is limited by the number of stator blades and the maximum local flow turning possible through the stator blade row.

Replace present paragraph [0060] with the following new paragraph [0060]:

[0060] By way of illustration of other possible applications of the invention, the centrifugal pump illustrated in FIGURE <u>12</u> [[8]] is an example of an embodiment in which the cascade of lifting elements is stationary and the device for directing fluid into the cascade rotates. A centrifugal pump 150 comprises a centrifugal impeller 152 with a plurality of impeller elements [[152]] <u>153</u>$_{M,K}$, which will be described in more detail shortly. The impeller elements are arranged around a hub 154 capable of rotating on an axis 156 in the direction of the arrow A at an angular velocity Ω. As is conventional, the working fluid enters the impeller at a radially inward location near the hub 154, and the impeller elements direct the flow to the impeller outlet disposed at its periphery. The flow exits the impeller outlet and is directed into a diffuser (not shown). A cascade of lifting elements 158 is disposed around the periphery of the impeller, and each lifting

element 158 has an airfoil shape. The cascade of lifting elements has an inlet into which is directed working fluid exiting the impeller outlet. A typical compressor/pump with this basic design is shown in U.S. Patent No. 5,368,440 to Japikse et al.

Replace present paragraph [0061] with the following new paragraph [0061]:

[0061] In accordance with the present invention, the conventional design is altered so that the impeller device for directing fluid into the cascade inlet comprises impeller elements 153 with cyclically varying configurations arranged in M groups, each having K impeller elements. The notation in FIGURE 12 [[8]] corresponds to that in FIGURE 3, except that M = 2 and K = 8 in FIGURE 12 [[8]]. Therefore, each of impeller elements $153_{M,1}$ directs the flow toward the cascade of lifting elements 158 at an angle θ_1; each of impeller elements $153_{M,2}$ directs the flow toward the cascade of lifting elements 158 at an angle θ_2; each of impeller elements $153_{M,3}$ directs the flow toward the cascade of lifting elements 158 at an angle θ_3; each of impeller elements $153_{M,4}$ directs the flow toward the cascade of lifting elements 158 at an angle θ_4; each of impeller elements $153_{M,5}$ directs the flow toward the cascade of lifting elements 158 at an angle θ_5; each of impeller elements $153_{M,6}$ directs the flow toward the cascade of lifting elements 158 at an angle θ_6; each of impeller elements $153_{M,7}$ directs the flow toward the cascade of lifting elements 158 at an angle θ_4; and each of impeller elements $153_{M,8}$ directs the flow toward the cascade of lifting elements 158 at an angle θ_8. The exit angle θ of the impeller elements within each group M gradually changes around the periphery of the impeller; in that fashion the exit angles θ of the different impeller elements 153 correspond to the turning angles θ of the different stator in FIGURE 3. In a centrifugal

pump or compressor the pressure rise can be enhanced by increasing the lift provided by the cascade of lifting elements 158. Accordingly, the invention provides angles θ_1 to θ_8, chosen such that each lifting element 158 experiences flow cycling like that depicted in FIGURE 4, in which the flow repeatedly begins to separate from each lifting element and then reattaches.

Amend the Abstract of the Disclosure to read as follows:

A compressor or pump employs principles of unsteady delayed stall to enhance the head increase produced by the compressor or pump. Plural airfoil-shaped lifting elements are spaced from each other in a cascade and the fluid is directed into the cascade by a device that varies a parameter of the flow relative to each lifting element in repeating cycles to cause the flow relative to each lifting element to begin to separate from the lifting element and then reattach thereto during each cycle. The ~~For example, when the invention is applied to an axial flow compressor, the~~ cascade can comprise ~~comprises~~ an axial flow impeller with plural impeller blades arranged around a hub capable of rotating on an axis. The device for varying the flow parameter can be a stator with a plurality of stator blades upstream of said impeller, or a second, counter-rotating axial flow impeller. In either case, the parameter is a flow angle at which the flow is directed to the downstream impeller. The disclosed approach ~~invention~~ is applicable to any method, and any apparatus that incorporates structure, in which flow is directed to a cascade of lifting elements in a manner whereby the flow relative to each lifting element periodically begins to separate from the lifting element and then reattaches thereto.